COMPARING AIR QUALITY MODEL PERFORMANCE FOR PLANNING APPLICATIONS

Michel Vedrenne[1,2], Julio Lumbreras[1], Rafael Borge[1], Alain Clappier[3], Philippe Thunis[4], and Mª Encarnación Rodríguez[1]

[1]Department of Chemical & Environmental Engineering, Technical University of Madrid (UPM), Madrid, Spain
[2]Air & Environmental Quality, Ricardo Energy & Environment, London, United Kingdom
[3]Laboratoire Image Ville Environnement, Strasbourg University, Strasbourg, France
[4]Joint Research Centre, European Commission, Ispra, Italy

Abstract: The current policy making needs for emission abatement of air pollutants in Europe call for having simple yet robust tools that allow evaluating the effect of measures and sorting those that produce the most significant effects. As a result, the FAIRMODE Planning Working Group (WG4) seeks to develop a consistent framework for streamlining the understanding of models in order to identify more efficiently the relationship between changes in emissions and their effect in ambient concentration through a series of indicators or potencies. The comparison of sector-specific potencies was carried out using the Delta Tool for the AERIS integrated assessment model for the Iberian Peninsula and the SERCA modelling system, on which it is based. Air quality observations from 11 monitoring stations located in Spain and Portugal were used as independent comparison dataset, focusing on a winter and summer month (January and August), as well as on an annual basis. The comparison revealed that the main difference between AERIS and SERCA is the description of the non-linear relationship between changes in emissions and the formation of secondary pollutants (e.g. secondary particles, ground-level ozone). This is a consequence of the linear simplification that was used to construct AERIS, as opposed to the deterministic formulation that is contained in SERCA and is basically composed of the WRF-CMAQ ensemble. The comparison also suggested differences in the ability to reproduce seasonal variations of pollutants, something which is a consequence of the annual character of AERIS. However, AERIS is able to reproduce its parent air quality model (SERCA) and complies with the general modelling performance requirements stipulated under FAIRMODE. Moreover, its simplified approach, as evidenced by the values of the potencies allows identifying the interactions between emissions and concentrations, facilitating choosing mitigation measures depending on the abatement needs. Additionally, the ability of AERIS to reproduce ambient concentrations under a simplified approach makes it a robust alternative to SERCA for informing policy making and planning in Spain.

Key words: *Integrated Assessment Modelling, Air Quality Planning, Policy Making, Model Evaluation, FAIRMODE*

INTRODUCTION

The use of air quality models for supporting the selection of cost-effective measures to reduce air pollution has been an essential part of environmental policy planning in Europe, in order to assess compliance with the targets of Directive 2008/50/EC and to ensure that the associated impacts are kept at a minimum (EEA, 2011). While reducing ambient levels of airborne pollutants is often the objective of the process, decision makers are only able of acting on a given number of emission sources and are limited by technical or financial constraints. Although the ownership of air pollution models traditionally lies within the scientific community, the fact that policy makers are evermore requiring their use for the appraisal of abatement policies highlights the need of constructing simplified yet robust tools that simplify the dialogue at the "science-policy" interface (Carnevale et al., 2016).

The Forum for Air Quality Modelling (FAIRMODE) initiative aims for the establishment of a conceptual framework that illustrates the complex relationships between emissions and concentrations, in order to increase the transparency of a model and easily identify the abatement potential of measures without the need of configuring and running the model itself (Thunis et al., 2015). An essential part in the construction of policy-tailored air quality modelling tools is evaluating against a deterministic model (usually its originating "parent" model) in order to demonstrate that the difference in performance is minimal or at least that there is a balance between the loss of performance and the gain in swiftness in the policy-science interaction.

The AERIS integrated assessment model was designed to provide national-level policy support for Spain and Portugal relying on parameterisations based on source-receptor matrices of the SERCA modelling system, composed by the WRF-SMOKE-CMAQ models. In previous studies the performance of AERIS was contrasted against that of SERCA in (i) reproducing average concentrations of airborne pollutants and (ii) in responding to individual and simultaneous changes of emission sectors (Vedrenne et al., 2013; 2014). In this work however, an evaluation of the response of ambient concentrations as a result of variation in emissions is carried out at specific receptors throughout the Iberian Peninsula (e.g. monitoring locations). The results from this evaluation will allow identifying performance differences associated with the simplifications of AERIS with respect to SERCA and will illustrate the dependency degree of the concentrations of specific airborne pollutants with variations in the emissions of precursors. This evaluation is especially useful for differentiating the interplay of the emissions of specific precursors in the formation of secondary pollutants.

To this respect, the methodology for dynamic evaluation proposed within WG4 of FAIRMODE allows quantifying these dependencies in the form of potencies, which is defined as the elasticity of the change of emissions of one or more precursors to the change in concentration of a given pollutant (Thunis et al., 2015). The FAIRMODE methodological framework for dynamic evaluation allows carrying out these model comparisons with the Planning version of the Delta Tool, which provides the output in a graphical and comprehensive format. The details of the comparison of AERIS against SERCA are described in the following sections.

MATERIALS AND METHODS

Description of Models

The AERIS model is an integrated assessment model conceived for Spain and the Iberian Peninsula, which addresses air quality variations as a function of percentual variations of emissions against a reference scenario. The model also allows assessing the effect of policy on the air quality metrics defined by Directive 2008/50/EC for numerous pollutants (SO_2, NO_2, NH_3, PM_{10}, $PM_{2.5}$ and O_3). The model is also able to determine the impacts on human health, ecosystems and vegetation produced by the concentrations of these pollutants (Vedrenne et al., 2015). AERIS was built by parameterising the response of the SERCA model.

The SERCA model is a multi-scale air quality model composed of the Weather Research and Forecast (WRF) model for the determination of meteorology, the SMOKE emissions processor and the Community Multiscale Air Quality (CMAQ) model for modelling atmospheric chemistry and transport. The SERCA model has been especially configured to provide concentration of pollutants for the Iberian Peninsula and the city of Madrid and has been thoroughly used for policy support purposes at the national and local level (Borge et al., 2008; 2014).

Description of Methodology

The comparison of the performance of AERIS against its parent air quality model (SERCA) was carried out following the FAIRMODE Working Group 4 methodology for the assessment of models used for planning applications and specified in Thunis and Clappier (2014) and Thunis et al., (2015). This methodology relies on the concept of potency which is an indicator of the elasticity of concentration changes as a function of variation in emissions. The absolute potency is defined as in equation (1).

$$p_{\alpha}^{k} = \frac{\Delta C_{\alpha}^{k}}{\alpha E^{k}} \tag{1}$$

Where ΔC^{k}_{α} is the concentration change between the base case and the emission reduction scenario concentration, α is the reduction ratio of emissions and E^k are the emissions of precursor k over the area

A. To carry out the evaluation, a series of independent simulations in which the emissions of precursors are reduced either independently or contemporarily was required. Simulations with changing precursor emissions for the whole of Spain were carried out for the month of January 2007 with both SERCA and AERIS, with the objective of identifying the interactions between emissions and air quality levels.

These simulations consisted of:

- A base case simulation.
- Five simulations where the following precursors were decreased by 50%: nitrogen oxides (NO_x), sulphur dioxide (SO_2), ammonia (NH_3), primary particulate matter (PPM) and volatile organic compounds (VOC).
- Five simulations where the before mentioned precursors were decreased by 90%.
- Two simulations in which all 5 precursor emissions were reduced contemporarily by 50% and 90%.

The evaluation of these potencies was carried out for ground-level ozone (O_3) and fine particulate matter ($PM_{2.5}$) measured at 11 background monitoring locations in Spain from the EMEP network (Table 1). These stations were selected as their measurements are representative of the concentration values at the resolution of SERCA and AERIS (16 km). The analysis of absolute potencies and the output diagrams in this work was carried out using the Dynamic Evaluation function of the JRC Delta Tool. The total emissions for the determination of the potency for each of the precursors in Spain were obtained from the National Emissions Inventory for 2007.

Table 1. Selected monitoring stations for potency analysis

Station	Name	Latitude	Longitude
ES0011R	Barcarrota	38°28'22''N	6°55'14''W
ES0010R	Cabo de Creus	42°19'09''N	3°18'56''E
ES0009R	Campisábalos	41°16'27''N	3°08'33''W
ES0017R	Doñana	37°03°06''N	6°33'19''W
ES0014R	Els Torms	41°23'38''N	0°44'04''E
ES0008R	Niembro	43°26'21''N	4°50'60''E
ES0016R	O Saviñao	42°38'14''N	7°42'16''W
ES0013R	Peñausende	41°14'20''N	5°53'51''W
ES0015R	Risco Llano	39°31'15''N	4°21'11''W
ES0007R	Víznar	37°14'13''N	6°32'03''W
ES0012R	Zarra	39°04'58''N	1°06'03''W

RESULTS AND DISCUSSION

The results of the analysis explained in the sections above is presented in Figure 1 for fine particulate matter concentrations (PM2.5) and in Figure 2 for ground-level ozone (O_3). In the case of $PM_{2.5}$, model responses in SERCA are heavily dominated by the emissions of PPM and followed by the emissions of NO_x. In the case of the emissions of PPM, its dominance is significantly higher for episodes than for the average response. The rest of precursors do not show a substantial influence to $PM_{2.5}$ according to the model. In the case of AERIS, the resulting $PM_{2.5}$ concentrations are also influenced by PPM emissions, and to a greater extent by the emissions of the rest of precursors (NH_x and NO_x). While in the case of AERIS the modelling response is more linear as represented by the coincidence between both lines and central circles for both 50% and 90% variations, SERCA exhibits variations.

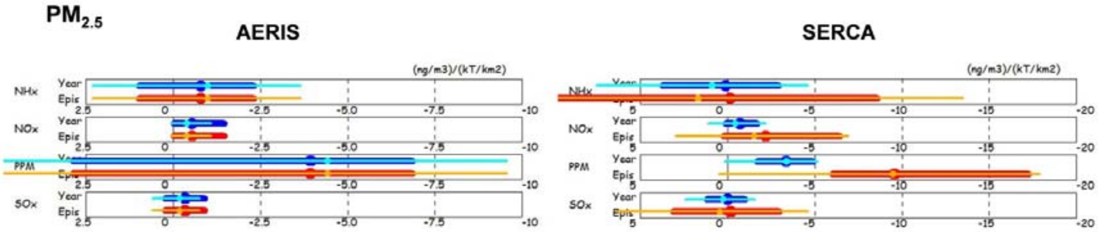

Figure 1. Comparison of $PM_{2.5}$ absolute potencies from AERIS and SERCA for Spain.

In the case of episodic events, and in particular for SERCA, the potencies obtained indicate the larger control that is available on abating high $PM_{2.5}$ episodes rather than average concentrations. When the objective of measures is controlling O_3, its levels are conditioned by NOx emissions principally, but the influence of VOC emission controls is also visible (Figure 2). The response of O_3 to other precursors different to NO_x or VOC was not studied due to the negligible effect that was reported in Thunis et al., (2015).

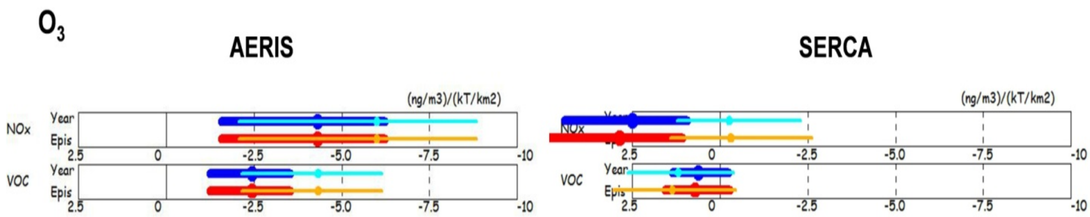

Figure 2. Comparison of O_3 absolute potencies from AERIS and SERCA for Spain.

The summary diagrams presented in Figures 1 and 2 show that there is a different degree of response to emission controls (variations) between the models despite the fact that AERIS is derived from SERCA. The main reasons for the observed discrepancies are the following:

1. Temporal resolutions. AERIS is an “annual model”, which means that it cannot produce hourly outputs in the way that a deterministic model such as SERCA does. In the case of this work and for the month of January, only one value (the monthly average concentration of O_3, $PM_{2.5}$) was produced; this is the reason why there are no differences between the average and the episodic lines in the diagrams.
2. Statistical parameterisations. AERIS has been developed through a series of source-receptor matrices that provide a shortcut for estimating air pollutant concentrations as a function of changes in emissions. These parameterisations have been developed individually for a number of sectors which correspond to the majority of emissions (and whose sectors are more likely of being affected by policy) in the domain and there is an accumulation of accuracy loss associated with their simultaneous variation. In the case of SERCA, variations are applied on all sources across the domain irrespectively. Additionally, AERIS considers that the relationships between the changes in emissions of NO_x and the resulting concentrations of NO_2 are linear.

CONCLUSIONS

The dynamic evaluation of the model outputs of AERIS and SERCA has allowed identifying the differences in the dependencies that exist between the concentrations of PM2.5 and O3 and the emissions of precursors. In both cases, similarities in the dominance of changes in the emissions of precursors can be seen; in particular, PPM and NOx seem to play a substantial role in the formation of PM2.5 and O3 respectively for both models. Differences have been seen in the way both models deal with episodic and average behaviours, being this a limitation of AERIS as it has been built as an annual model. The other sources of observed differences are related with modelling assumptions, with the statistical parameterisations and with the fact that AERIS does not consider the totality of the emissions of a specific precursor across the entire domain.

REFERENCES

Borge, R., Lumbreras, J., Rodríguez, M.E., 2008. Development of a high-resolution emission inventory for Spain using the SMOKE modelling system: a case study for the years 2000 and 2010. *Environmental Modelling & Software* **23**, 1026-1044.

Borge, R., Lumbreras, J., Pérez, J., de la Paz, D., Vedrenne, M., de Andrés, J.M., Rodríguez, M.E., 2014. Emission inventories and modeling requirements for the development of air quality plans. Application to Madrid (Spain). *Science of the Total Environme*nt **466-467**, 809-819.

Carnevale, C., Douros, J., Finzi, G., Graff, A., Guariso, G., Nahorski, Z., Pisoni, E., Ponche, J.L., Real, E., Turrini, E., Vlachokostas, Ch., 2016. Uncertainty evaluation in air quality planning decisions: a case study for Northern Italy. *Environmental Science & Policy.* In Press. Corrected Proof.

EEA, 2011. The Application of Models under the European Union's Air Quality Directive: a Technical Reference Guide. Technical report No 10/2011.

Thunis, P., Pisoni, E., Degraeuwe, B., Kranenburg, R., Schaap, M., Clappier, A., 2015. Dynamic evaluation of air quality models over European regions. *Atmospheric Environment* **111**, 185-194.

Thunis, P. and Clappier, A., 2014. Indicators to support the dynamic evaluation of air quality models. *Atmospheric Environment* **98**, 402-409.

Vedrenne, M., Borge, R., Lumbreras, J., de la Paz, D., Rodríguez, M.E., 2013. Development and implementation of an air quality integrated assessment model for the Iberian Peninsula. In: R. San José, J.L. Pérez (Eds.), Proceedings of the 15th International Conference on Harmonisation Within Atmospheric Dispersion Modelling for Regulatory Purposes (HARMO) (2013) ISBN 978-84-695-7353-5

Vedrenne, M., Borge, R., Lumbreras, J., Rodríguez, M.E., 2014. Advancements in the design and validation of an air pollution integrated assessment model for Spain. *Environmental Modelling & Software* **57**, 177-191.

Vedrenne, M., Borge, R., Lumbreras, J., Conlan, B., Rodríguez, M.E., de Andrés, J.M., de la Paz, D., Pérez, J., Narros, A., 2015. An integrated assessment of two decades of air pollution policy making in Spain: Impacts, costs and improvements. *Science of the Total Environment* **527-528**, 351-361.